The Study of Physics and Safety Characteristics for In-Hospital Neutron Irradiator(IHNI)

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ABSTACT： The IHNI is designed with low-enrichment ^{235}U (LEU) for Boron Neutron Capture Therapy (BNCT) based on Miniature Neutron Source Reactor (MNSR). The IHNI, operated with thermal power 30kW, is an under-moderated reactor of pool-tank type, and UO_2 as fuel, light water as coolant and moderator, and metallic beryllium as reflector. The paper gives the physics and safety characteristics of IHNI. The physics characteristics include those parameters of the criticality and the beam port used for BNCT. The safety characteristics compare the safety parameters between reactor core of LEU and HEU. The result shows that LEU could meet the requirements of criticality and flux at exit of each beam. Furthermore, the better safety characteristics could approach by adopting the LEU in comparison with HEU.
Key Words: MNSR, LEU, BNCT

1 Introduction

In order to meet the application requirements of Boron Neutron Capture Therapy (BNCT), China Institute of Atomic Energy (CIAE) decide to design a new reactor, used for In-Hospital Neutron Irradiator (IHNI) and based on Miniature Neutron Source Reactor (MNSR) It should be designed with upgraded reactor core with LEU since Original MNSR is design with HEU. The reactor will adopt current configuration of complex, present configuration of fuel (size undecided) and cooling method of MNSR. So, it is necessary to design a reactor core to meet the requirements of criticality characteristics and power distribution and safety characteristics. This paper will introduce the physics and safety characteristics of IHNI, excluded thermal-hydraulics since the reactor power is low.

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2 Physics characteristics

When the fuel rods are replaced with low enrichment uranium, the quantity and the arrangement of rods are also changed for assurance the criticality of the reactor. At the same time, the side-shields of the core are adjusted to fit the demand of facilities.

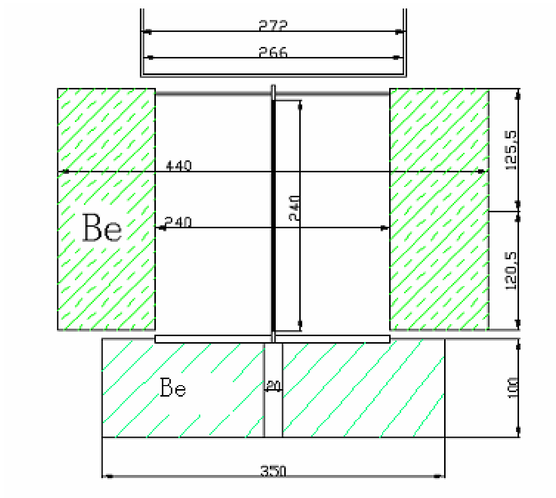

Fig.1 The structure of INHI

Fig.1 shows the frame of reactor in INHI. However, which percent of enrichment of uranium will be adopted and how many fuel rods will be necessary are optimized considering the criticality, the life-time of the reactor, the flux, etc.

A large number of optimizing calculations have been done through program MCNP for the material, geometry and size of the neutron energy regulator, neutron reflector, and the gamma ray attenuator. The reactor design is gained of the maximum ratio value of irradiation flux (at port) to reactor unit power. The final parameters of the reactor are as follow, 12.5%wt enrichment of uranium-235, 350 lattices of fuels elements are prepared. The arrangement of fuel rods is shown in fig.2. The final critical results will be listed in table 1. From the result, it is available for the criticality and reactivity control for safe operation.

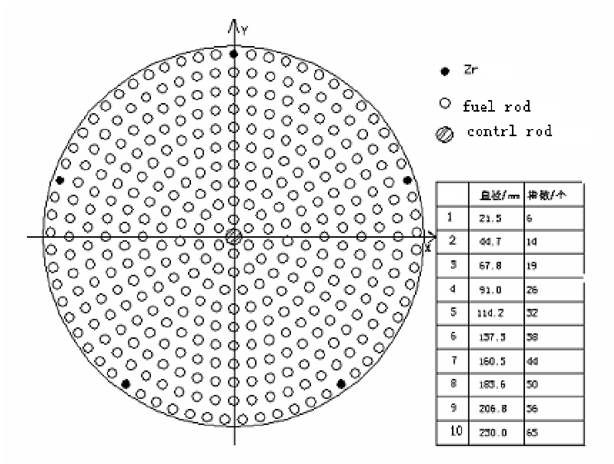

Fig.2 The arrangement of fuel in INHI

Tab.1 Results of critical calculation

Cases		Keff	reactivity（mk）
345 fuels rods	Without neutron beam facilities and reactivity controllers	1.05944	
	Thermal neutron beam facility are considered without epithermal neutron beam facility and reactivity controllers	1.05894	-0.45
	Epithermal neutron beam facility are considered without thermal neutron beam facility and reactivity controllers	1.05078	-7.8
	Both the two sets of neutron beam facilities are considered without reactivity controllers	1.05078	/
	With safe rods	1.04441	-5.8
	With reactivity adjusters	1.03681	-6.4
	With control rod（4mm）	1.04419	-6.0
	With control rod（5mm）	1.04290	-7.2
	With up beryllium reflector	1.07059	17.6

The distance from the core to the exit of radiation filter is about 150cm. The result of epithermal neutron beam is listed in table 2 for example, when the power of the reactor is 30kW.

Tab.2 the results of the exit of epithermal neutron beam

Characteristics	Unit	Results
ϕ_{th} **(<0.4eV)**	$n.cm^{-2}.s^{-1}$	1.56×10^{7} (±2.29%)
ϕ_{epi} **(0.4eV-10keV)**	$n.cm^{-2}.s^{-1}$	4.00×10^{8} (±0.56%)
ϕ_{f} **(>10keV)**	$n.cm^{-2}.s^{-1}$	3.60×10^{7} (±1.69%)
$\boldsymbol{\phi_n}$	$n.cm^{-2}.s^{-1}$	4.52×10^{8} (±0.54%)
$\boldsymbol{\phi_\gamma}$	$\gamma .cm^{-2}.s^{-1}$	1.91×10^{7} (±1.35%)
$\dot{D}_f/\phi_{epi}$	$Gy.cm^2$	5.60×10^{-13}
$\dot{D}_\gamma/\phi_{epi}$	$Gy.cm^2$	1.95×10^{-13}
ϕ_{epi}/ϕ_{th}		25.59

J_n^- / ϕ_n		0.830
J_n^-	$n.cm^{-2}.s^{-1}$	3.75×10^8

As the result, neutron flux at the exit of the radiation filters of two neutron beams is met the requirements, $2.14 \times 10^9 n/cm^2$-s for thermal and $4.0 \times 10^8 n/cm^2$-s for epithermal.

3 Safety characteristics

Safety characteristics are analyzed by using RELAP5/SCDAPSIM/MOD3.2. The most severe design basis accident of INHI is rod withdrawal accident. If the control rod is withdrew out of the core instantly at zero power, the reactor will still be safe and the power will stabilize to a certain level due to natural circulation ability and negative reactivity coefficient. The results are showed in Fig 3 to Fig 6.

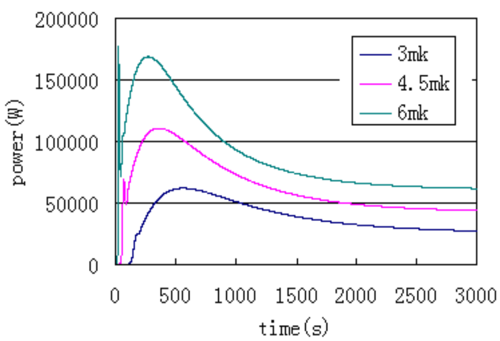

Fig 3 reactor power

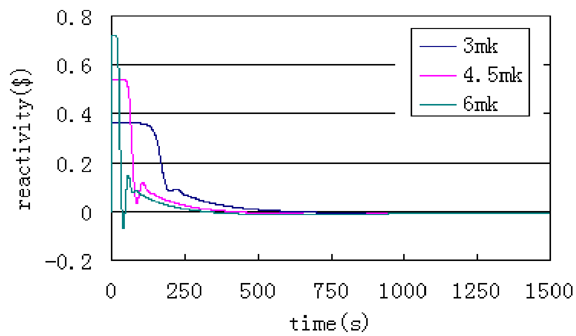

Fig 4 reactivity

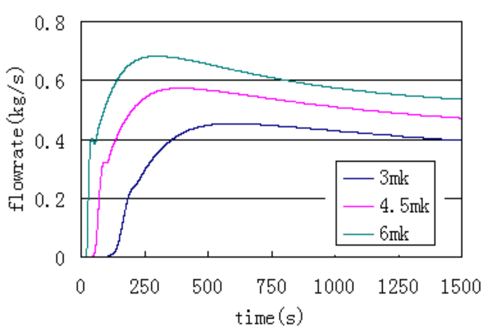

Fig 5 natural circulation flow rate

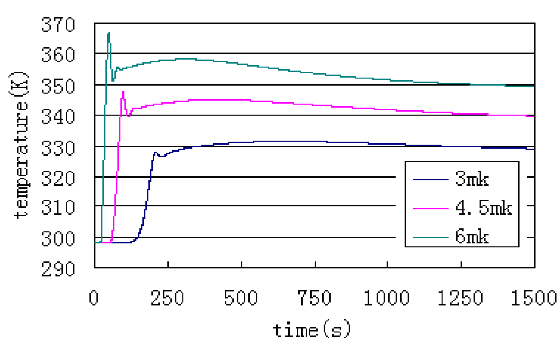

Fig 6 temperature at core outlet

The fuel enrichment will affect the transient of rod withdrawal accident. Fuel temperature coefficient of HEU is about 1/20 of that of LEU. When the rod withdrawal accident occurs, the power growth will be inhibited by fuel temperature coefficient firstly. The transient process of reactor power of HEU and LEU is compared in Fig 7, when the amount of reactivity insertion at zero power is 4.5mk. It shows that a core loaded with LEU fuels has better safety characteristics.

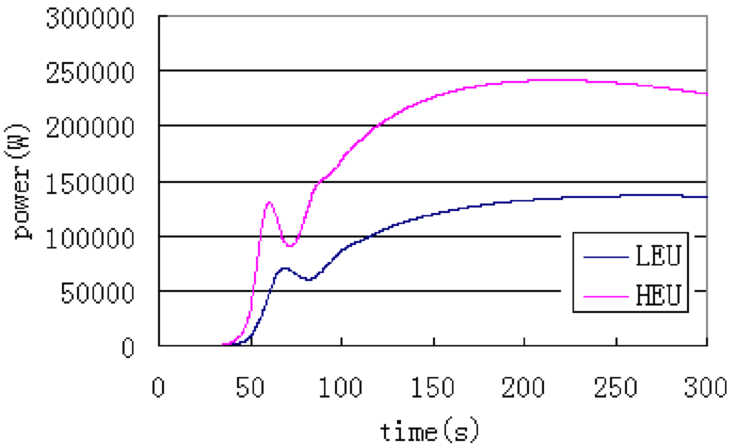

Fig 7 reactor power

4 Conclusion

The present design of both the reactor core and two sets of neutron beam equipment achieve the requirements of the applications, especially meet the purpose of reduce uranium enrichment. The study also provides a new application direction of BNCT for MNSR, which is different with original usage of NAA, training and teaching, testing of nuclear instrumentation.

For the most severe design basis accident of INHI, rod withdrawal accident, the reactor of IHNI will still be safe. Furthermore, the comparison of safety characteristics between reactor core of HEU and that of LEU show that the latter will have obviously better safety characteristics.